Autonomous and Connected Vehicles

Preparing for the Future of Surface Transportation

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HDR

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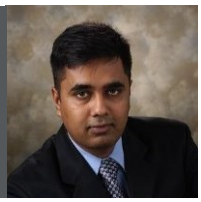
Bernie Arseneau is the Director of Traffic Management Systems located in Minneapolis, MN. Bernie provides a strategic focus around the development of long-term tactical plans for Traffic Management Systems, specifically in the areas of managed lanes, traffic safety and intelligent transportation systems (ITS). He joined HDR following 30 years of service to the Minnesota Department of Transportation (MnDOT), where he last served as deputy commissioner/chief engineer. He has been active nationally with the American Association of State Highway and Transportation Officials (AASHTO) and the Transportation Research Board (TRB). He was a member of AASHTO's Standing Committee on Highways and its Standing Committee on Highway Traffic Safety, and served on AASHTO's National Committee on Uniform Traffic Control Devices (NCUTCD) Executive Board. He served as vice chair of AASHTO's Standing Committee on Performance Management Task Force on MAP-21 National Performance Measures. Additionally, he chaired TRB's Strategic Highway Research Program (SHRP) 2 Regional Operations Forum for Advancing Systems Operations, Management and Reliability—Technical Expert Task Group.



Santanu Roy, PTP

Transportation Planning Manager, Travel Demand Modeling Practice Lead

Santanu Roy is a Transportation Planning Manager with a strong technical foundation and the ability to bring innovation, national experience and exceptional client service to each project. He provides statewide Transportation Planning services to clients for HDR in Florida. As the Travel Demand Modeling Practice Lead at HDR, Mr. Roy works with all HDR offices and provides directions to implement the company's vision to expand and provide services to the associated market sectors. Mr. Roy has served on a variety of transit projects, intermodal/ multimodal studies, corridor studies, long-range transportation plans, master plans, toll feasibility studies, managed lane studies, interchange justifications, development of regional impacts and other studies around the country. He was appointed by the Florida Department of Transportation (FDOT) to serve as the Modal Working Group Secretary for the Florida Automated Vehicles Initiative. He is also involved in several Transportation Research Board (TRB) committees and the Florida Model Task Force committees.

Joshua Salazar, PE

Senior Project Manager

Joshua Salazar is a Senior Project Manager who recently moved from South Florida to the Ann Arbor, MI, office. He participates in the Michigan Connected and Automated Vehicles Working Group with the Michigan DOT, academic institutions, technology companies and the automotive industry. In his 11 years in the industry, Mr. Salazar has managed corridor studies for a variety of NEPA projects, transit corridors and managed lanes projects. He also develops multimodal solutions for projects integrating technology and innovative design, and has experience in integrated corridor management of roadway networks, bicyclists/pedestrians, traffic management centers, freeway operation and transit services with Transit Signal Priority (TSP) and queue jumps. Mr. Salazar has extensive Florida managed lanes experience, having established the process for evaluating managed lane access points and operational scenarios for dynamic tolling on over 100 miles of managed lanes systems. He also works with multi-disciplined teams to strategically scope, evaluate and prioritize projects with short- and long-term implementation strategies.

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Senior ITS Project Manager

Joey Yang is highly skilled in the design, implementation, integration, and deployment of large-scale Intelligent Transportation Systems (ITS), Advanced Traffic Management Systems (ATMS), Transportation Management Centers (TMC), and Electronic Toll Collection (ETC) projects. His extensive design experience includes PS&E, systems engineering analysis, implementation and testing of National Transportation Communications for ITS Protocols (NTCIP), Open Road Tolling (ORT), Active Traffic Management (ATM), communications systems, power distribution networks, lighting control, and traffic control equipment. He has in-depth knowledge in industry standards, including IEEE, NTCIP, MUTCD, NEMA, ATC, IES and NFPA. He also specializes in the design and implementation of central/field communications, traffic control equipment, communications devices, traffic controller hardware and software, Advanced Solid-state Traffic Controller, transit signal priority, CCTV cameras, DMS/VMS signs, traffic detectors and electronic tolling equipment.

Abstract

Autonomous and Connected Vehicles: Preparing for the Future of Surface Transportation

What was once considered “futuristic” technology seen only in movies is now challenging the traditional standards for transportation safety, mobility and the environment, similar to how the automobile has revolutionized transportation. Autonomous Vehicle (AV) and Connected Vehicle (CV) initiatives are becoming more prominent, and we are seeing innovative tech-safety features from the automotive industry. Technology companies (e.g., Google Car) and savvy government agencies are also partnering to further drive change. Over the past 15-20 years, expectations for advanced transportation options have expanded, and it is critical that today’s transportation decision makers be well positioned for the next stage of opportunities.

Contents

Figures

Introduction

What are Autonomous and Connected Vehicles?

The future of transportation technology is already upon us with tangible examples of futuristic travel options increasing each year. Significant investments from public, private and institutional parties have developed systems and technology to mitigate the user errors that result in loss of life on the transportation network. Wireless communication devices have been developed for vehicles to communicate operational conditions between and among each other, as well as with the adjacent infrastructure, to perform automated driving functions. Safety is the paramount objective of the developing technologies that would navigate the transportation network, reducing human errors. These technological advances will also greatly enhance the mobility of people and goods. Our future transportation networks must evolve and transform to adopt this technology into the planning, design and construction of transportation projects. The challenges for our industry are to formulate the public-private partnerships that will be critical to the successful integration and implementation of these technologies into our everyday world of transportation services and facilities. Understanding the scope of new technologies is the first step.

Autonomous Vehicles (AV)

Vehicles that can perform all driving functions with or without human drivers, also called self-driving or driverless vehicles.

Connected Vehicles (CV)

Vehicles with advanced technology to communicate with external systems.

Autonomous Vehicle Technology

Technology

Pioneering technology currently exists for vehicles to independently sense and maneuver without human control. Advancements in technology over the past 30 years have resulted in innovative detection, communications and processing of automated decisions with a variety of applications. The automotive industry has invested research and development strategies to outfit personal automobiles with the most modern technologies available. Personal convenience technologies such as in-vehicle Wi-Fi and digital dashboard controls have also steadily become mainstream with the release of more recent vehicle models. The advancements in modern technology have allowed the comprehensive integration of essential systems and data for autonomous vehicle operations. This allows the vehicles to process decisions based on defined criteria informed by actual conditions, such as the following:

- Global Positioning System (GPS) – Satellite-based global location and time reference of objects (vehicles) for accurate and constant position tracking. Traditionally, this has been utilized with mapping and/or direction services for processing decision information between user-defined destinations.
- Inertial Navigation System – Monitors and calculates positioning, direction and speed of a vehicle with motion and rotation sensors on-board.
- Laser Illuminated Detection And Ranging (LIDAR) – Laser detection sensors to identify surrounding objects, or terrain, with data for precision measurements of distance to the objects.

The synchronization of these advanced positioning systems collectively provide the decision-making data points that are necessary for an autonomous vehicle to be aware of its position and movements in relation to the surrounding conditions in order to traverse the course from origin to destination.

Automation employs control systems with minimal or reduced human intervention. In addition to traditional automotive manufacturers, technology companies have been developing and introducing their own vehicles in the race to provide accessible and reliable personal autonomous vehicles. The Google Car prototype demonstrates an innovative approach to vehicle design emphasized by a self-propelled, self-directed experience with no traditional driver controls accessible. Passengers in the car are essentially along for the ride with no gas pedal, no brake pedal and no steering wheel available to take control of the vehicle. The destination is passenger defined with the route determined by the synthesis of data obtained by the vehicle. The most recent demonstrations cite a 25 mph limitation for safety, but allow one to conservatively experience the technology.

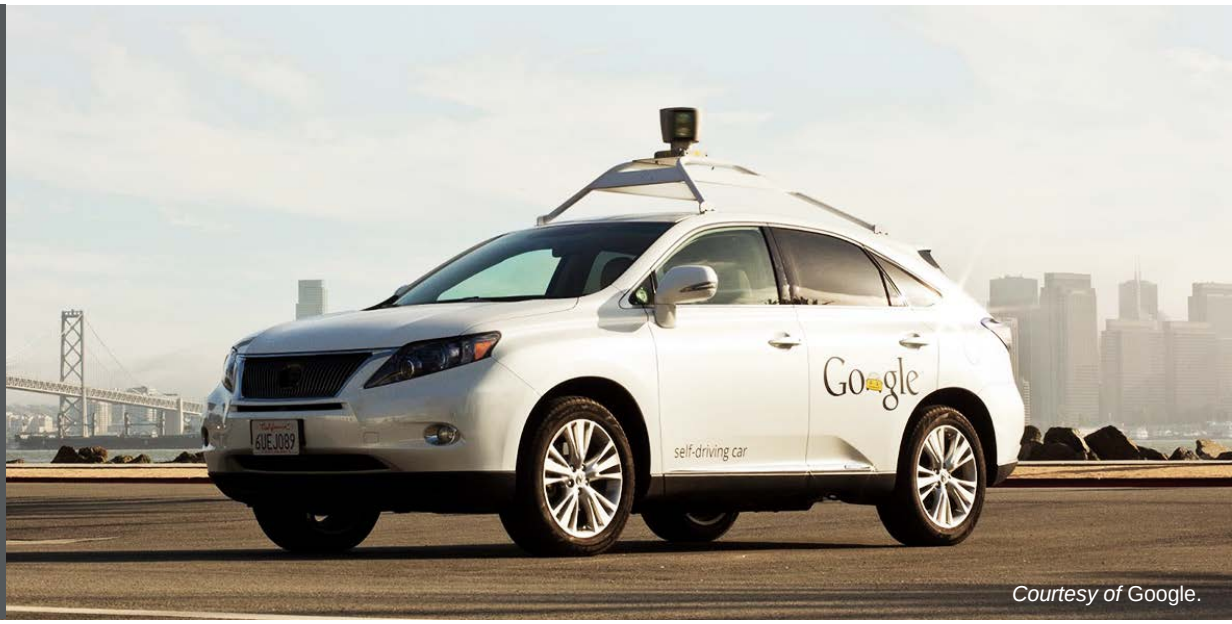


Figure 1. The Google Car

Courtesy of Google.

Existing Today

Prototype vehicles have been developed and have been tested in various markets around the globe. The challenges for regulatory and public agencies have been to fully define the “rules of the road” for integrating AV operations on all transportation facilities, and to understand the liabilities and responsibilities that may arise when a “driver” is to be held accountable for a self-driving vehicle. The lack of regulation is limiting the market penetration of AV; however, preparations have been made to standardize the definitions within the field to enable staggered acceptance.

In the United States, the National Highway Transportation Safety Administration (NHTSA) has already defined distinct classification levels of vehicle automation. NHTSA and industry partners have strived to encourage an organized fashion to which the emerging technologies are accounted for and additional resources are invested toward the goal of self-driving cars, or autonomous vehicles.

- Level 0 – The driver completely controls the vehicle at all times, with some automated functions available. Few modern vehicles actually fit this description, considering most cars on the road have some automated functions (cruise control, ABS, automatic transmission, etc.). The future is cars with the technology to relieve the driver from actually driving.

- Level 1 - Individual vehicle functions are automated, such as automatic braking.
    - Example: For automatic braking, the automated function occurs through detection and calculation of deceleration to determine critical actions to decelerate and avoid a collision approaching an object or unexpectedly stopped/slower vehicle.
- Level 2 – At least two automated technological functions occur in unison, such as adaptive cruise control in combination with lane keeping.
    - Example: Adaptive cruise control in combination with lane keeping utilizes automation to maintain constant speeds with allowance for speed changes set when approaching slower vehicles without driver reaction necessary to reset the cruise control. In addition, lane keeping relies on detection of lane line buffer space to prevent drifting that may occur when drivers are less engaged during cruise control, or adaptation to other vehicles unexpectedly entering the lane.
- Level 3 – Auto-pilot option that the driver can fully cede control of all safety-critical functions in certain conditions. The car senses when conditions require the driver to retake control and provides a "sufficiently comfortable transition time" for the driver to retake control. A driver can elect to take their hands off the wheel for portions of the journey, such as traversing a rural area. Drivers are required to take back control for more complex situations, such as navigating stop-and-go traffic in urban areas with complex obstacles that could be encountered.
- Level 4 – Full automation requires the vehicle to perform all safety-critical functions for the entire trip, with the driver not expected to control the vehicle at any time. As this vehicle would control all functions from start to stop, including all parking functions, it could include unoccupied cars. The inside of the Mercedes F 015 (debuted at 2015 trade shows) provides an attractive and spacious area to ride in and interact with passengers. The front seats swivel to facilitate engaged experiences and conversation instead of focusing on active driving.

Looking Ahead

Major investments continue to be made by private industry, public agencies and educational institutions to establish a reality for personalized autonomous vehicles. Each year more new vehicle releases are introduced and equipped with additional automated safety features. Aftermarket options are also being made available. The U.S. Department of Transportation (USDOT) continues to promote partnerships with states and private interests to advance technical, policy and regulatory needs to accommodate AV deployment.

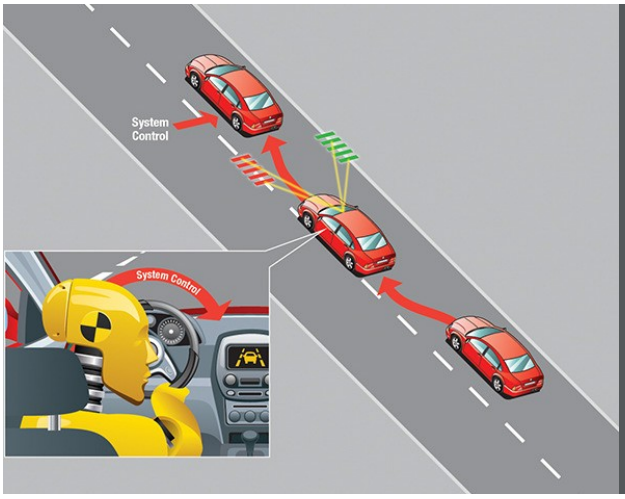


Figure 2. Lane Keeping

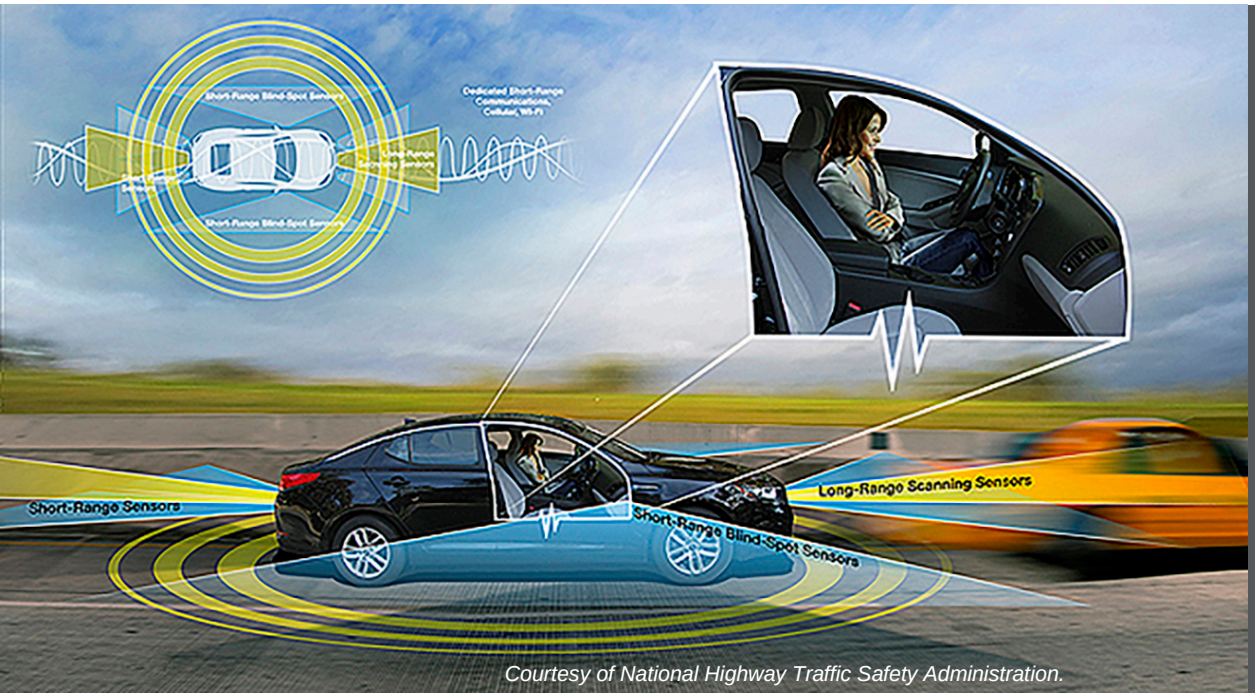
Picture Source: This infographic is reproduced with the permission of Transport Canada. Please refer to www.tc.gc.ca for more information.

Champions/Drivers

Automotive manufacturers continue to spend billions in research and development in their race to get reliable, autonomous vehicles in showrooms across the country. Technology companies are also charging the market place with expressed emphasis on a whole new kind of transportation (e.g., Google creating their own vehicles). Even advancements to enhance safety and automate certain functions aftermarket to vehicles are gaining ground and driving the future of safer fleets on the roadway. For example, Mobile Eye is a technology company that provides motion sensors and indicators for enhanced safety as an aftermarket

accessory to existing cars. Mobileye and other technology can detect potential conflict, notify drivers and utilize automated functions to react and enhance safety.

Test states like Michigan, California, Nevada and Florida have encouraging private investments, test bed projects and research to develop these concepts toward reality. The University of Michigan in Ann Arbor, MI, has constructed an entire isolated test facility called “M-City” for the purposes of advanced testing for Autonomous and Connected Vehicle scenarios intended to overcome current and future obstacles of mainstreaming AV.



Courtesy of National Highway Traffic Safety Administration.

Figure 3. On-board Technology Helps Perform Safety-critical Driving Functions

Benefits of Implementation

As exciting as it is to think about next-generation technology and human innovation, the key issue continues to be safety. AV has the potential to reduce 90% of the 32,000 annual fatalities resulting from US traffic crashes that are currently attributed to human operator error. Other key benefits championed by industry and legislatures continue to revolve around:

- Reduced Driver Costs (gas, ownership, property damage/insurance)
- Increased mobility for non-drivers (shuttle bus, elderly, teenagers)
- More efficient roadway and parking capacity (efficient roadway capacity, auto parking)

Connected Vehicle Technology

Technology

Connected vehicle technology leverages existing and anticipated ITS technology to allow advanced wireless technologies to communicate among vehicles, infrastructure, pedestrians and portable devices. The ITS Standards Program Strategic Plan[1] (2011–2014) describes ITS capabilities as follows:

> *"The application of advanced information and communications technology to surface transportation in order to achieve enhanced safety and mobility while reducing the environmental impact of transportation."*

The advancement of information and communications technology has enabled ITS to progressively change over the last 20 years. From copper wire to fiber optic and now to the high-speed wireless networks utilized today, the surface transportation systems have become more efficient and intelligent.

Figure 4, depicts the evolution of ITS driven by the advancement of technology. Today's ITS technologies consist of a range of communications electronics and computer technologies, such as systems that collect real-time traffic data and transmit information to the public via dynamic message signs and ramp meters to improve the flow of traffic on freeways. On arterials, traffic signals are synchronized and adjusted in response to active traffic conditions.

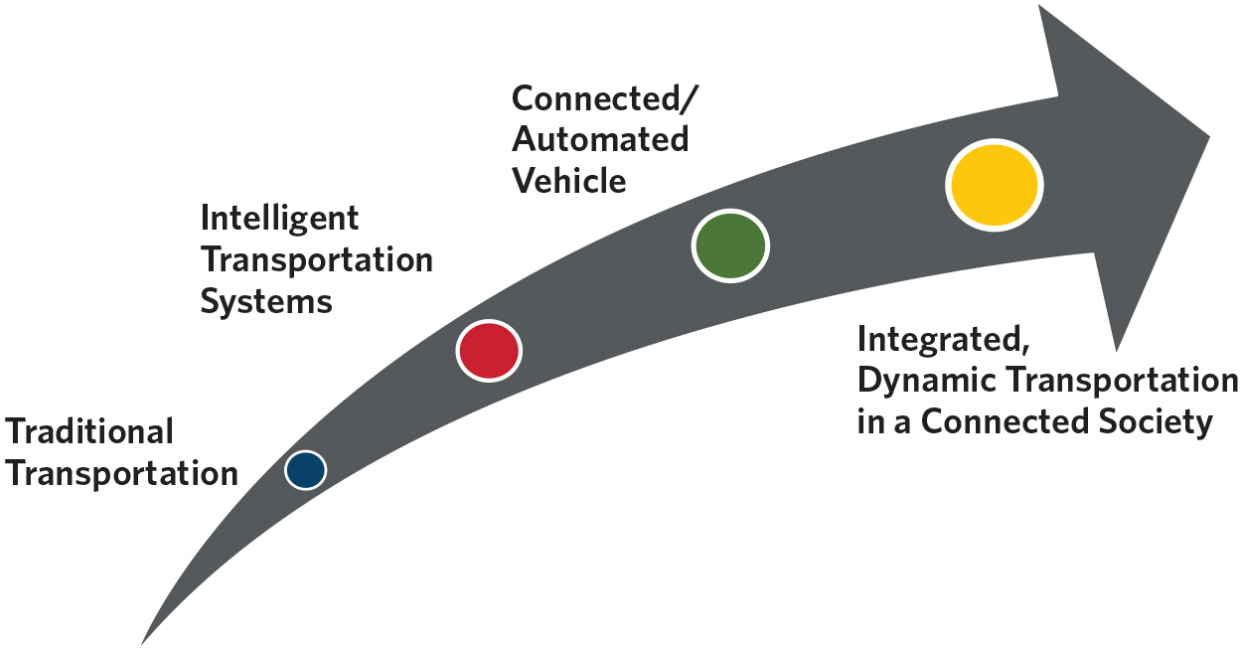


Figure 4. Connected Vehicle Next-Generation ITS

With the emergence of wireless vehicular networking technology in recent years, the next generation of ITS will focus on the connected vehicle technology to greatly improve safety and mobility while reducing the impact to environment. The connected vehicle technology is currently under research and pilot deployment, with wide public acceptance projected in the next five to 10 years.

This new technology resembles traditional ITS deployments, but is different in many ways. Connected technology requires vehicles to be cooperative, allowing data and information to be fused in real-time. It also

[1] The U.S. Department of Transportation (USDOT) Research and Innovative Technology Administration (RITA)\ITS Joint Program Office (ITS JPO), http://www.its.dot.gov/standards_strategic_plan/

requires a level of national interoperability and functionality not found in today's ITS deployments. Security and privacy needs for connected vehicles are far greater than for today's ITS.

As wireless technology continues to advance, an integrated, dynamic transportation system in a connected society will eventually become a reality.

Existing Today

Dedicated Short-Range Communications (DSRC) has enabled wireless communications since October 1999, when FCC allocated 75 MHz of spectrum in the 5.9 GHz band to be used by ITS. This band is critical for the implementation of Connected Vehicles on the transportation system.

In a connected vehicle environment, data is shared wirelessly among vehicles (Vehicle-to-Vehicle [V2V] communications) or between vehicles and infrastructure (vehicle-to-infrastructure [V2I] communications) using DSRC. This technology is similar to Wi-Fi, through which vehicles and infrastructure can transmit messages over a range of about 1,000 to 1,600 feet. Based on analysis of internal data and data received from other vehicles, a vehicle equipped with V2V technologies is able to issue a warning to its driver when a collision with another similarly equipped vehicle could occur. The range of V2V communications is not only greater than that of existing sensor-based technologies, but V2V technologies are also capable of alerting drivers to potential collisions that are not visible to existing sensor-based technologies, such as a stopped vehicle blocked from view or a moving vehicle at a blind intersection.

USDOT's early work on connected vehicle technologies has focused largely on V2I technologies. Recently the department has increased its focus on V2V technologies since they are projected to produce the majority of connected vehicle technology safety benefits, and they do not require the same level of infrastructure investment as V2I technologies. However, USDOT continues a strong focus on the development of V2I technologies.

An application of the connected vehicle technology that is gaining ground is the communication between vehicles and other, non-infrastructure devices (V2X), such as the Vehicle-to-pedestrian applications.

Connected Vehicle Applications - In order to achieve the goals to improve safety, mobility and reduce environmental impact, over 20 applications have been identified to date after years of research and development. Figure 5 provides a list of these applications in various states of maturity.

Figure 5. Connected Vehicle Applications

V2I Safety

- Red Light Violation Warning
- Curve Speed Warning
- Stop Sign Gap Assist
- Spot Weather Impact Warning
- Reduced Speed/Work Zone Warning
- Pedestrian in Signalized Crosswalk
- Warning (Transit)

V2V Safety

- Emergency Electronic Brake Lights (EEBL)
- Forward Collision Warning (FCW)
- Intersection Movement Assist (IMA)
- Left Turn Assist (LTA)
- Blind Spot/Lane Change Warning (BSW/LCW)
- Do Not Pass Warning (DNPW)
- Vehicle Turning Right in Front of Bus Warning (Transit)

Agency Data

- Probe-based Pavement Maintenance
- Probe-enabled Traffic Monitoring
- Vehicle Classification-based Traffic Studies
- CV-enabled Turning Movement & Intersection Analysis
- CV-enabled Origin-Destination Studies
- Work Zone Traveler Information

Environment

- Eco-Approach and Departure at Signalized Intersections
- Eco-Traffic Signal Timing
- Eco-Traffic Signal Priority
- Connected Eco-Driving
- Wireless Inductive/Resonance Charging
- Eco-Lanes Management
- Eco-Speed Harmonization
- Eco-Cooperative Adaptive Cruise Control
- Eco-Traveler Information
- Eco-Ramp Metering
- Low-Emissions Zone Management
- AFV Charging/Fueling Information
- Eco-Smart Parking
- Dynamic Eco-Routing (light vehicle, transit, freight)
- Eco-ICM Decision Support System

Road Weather

- Motorist Advisories and Warnings (MAW)
- Enhanced MDSS
- Vehicle Data Translator (VDT)
- Weather Response Traffic Information (WxTINFO)

Mobility

- Advanced Traveler Information System
- Intelligent Traffic Signal System (I-SIG)
- Signal Priority (transit, freight)
- Mobile Accessible Pedestrian Signal System (PED-SIG)
- Emergency Vehicle Preemption (PREEMPT)
- Dynamic Speed Harmonization (SPD-HARM)
- Queue Warning (Q-WARN)
- Cooperative Adaptive Cruise Control (CACC)
- Incident Scene Pre-Arrival Staging
- Guidance for Emergency Responders (RESP-STG)
- Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)
- Emergency Communications and Evacuation (EVAC)
- Connection Protection (T-CONNECT)
- Dynamic Transit Operations (T-DISP)
- Dynamic Ridesharing (D-RIDE)
- Freight-Specific Dynamic Travel Planning and Performance
- Drayage Optimization

Smart Roadside

- Wireless Inspection
- Smart Truck Parking

Source: National Highway Traffic Safety Administration (NHTSA)

Figures 6 (below) and 7 (following page), illustrate the timeline for connected vehicle activities. National Highway Traffic Safety Administration (NHTSA) announced the decision to move forward with V2V communication for light vehicles on February 3, 2014. The decision was based on research data and model deployment of nearly 2,800 equipped vehicles in Ann Arbor, MI, during a safety pilot that took place from August 2012 to February 2014.

Sponsored by DOT and conducted by the University of Michigan Transportation Research Institute, the safety pilot was designed to help determine the effectiveness of V2V technology at reducing crashes. Approximately 2,800 vehicles – a mix of cars, trucks and transit vehicles operating on public streets within a highly concentrated area – were equipped with integrated in-vehicle safety systems, aftermarket safety devices, or vehicle awareness devices, all using DSRC to emit wireless signals of vehicle position and heading information. Vehicles equipped with integrated in-vehicle or aftermarket safety devices had the additional design functionality of being able to warn drivers of an impending crash situation involving another equipped vehicle. The Safety Pilot Model Deployment included 27 roadside units covering 75 miles of roadway and was also designed to test V2I applications, including:

- Signal priority for transit and emergency vehicles
- Roadway maintenance
- Density of pedestrian traffic
- Traffic signal timing

Data from the model deployment is being archived and made available to researchers for evaluation and testing of applications beyond the testing period. The model deployment is the first test of this magnitude of V2V technology in a real-world, multimodal operating environment. The results of the safety pilot can be found at the NHTSA site. Search for "DOT HS 812 171 – Safety Pilot Model Deployment Test Conductor Team Report," and download the PDF.

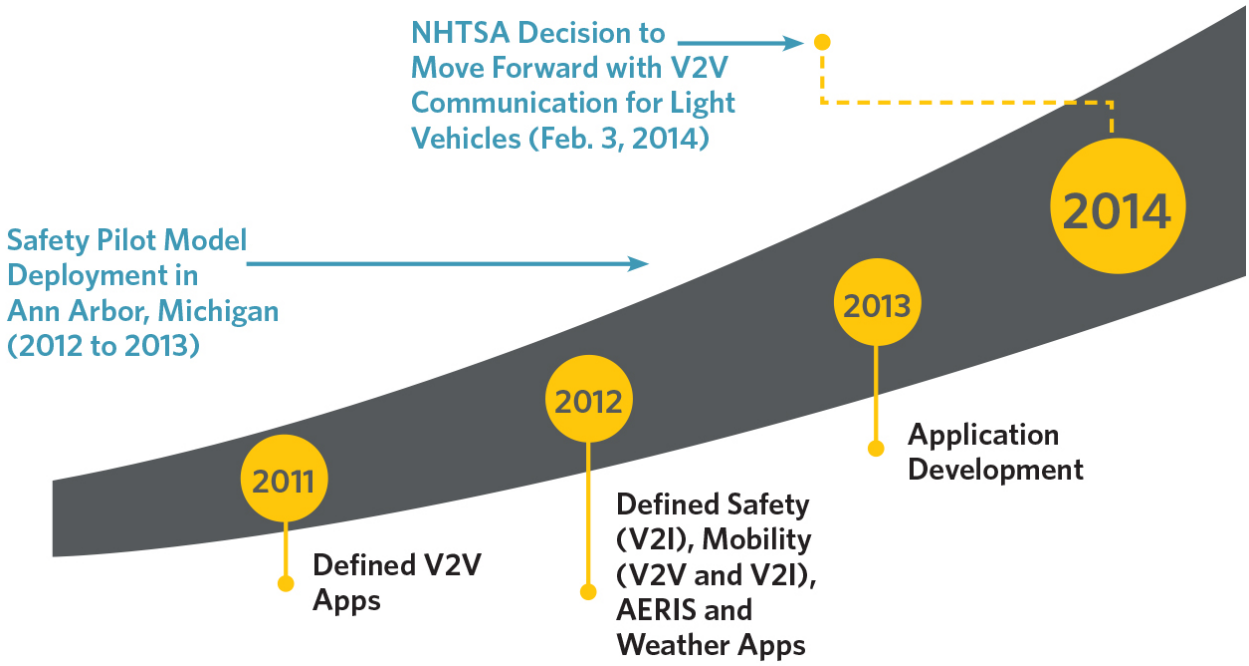


Figure 6. Connected Vehicle Model Deployment and NHTSA Rulemaking (2011 to 2014)

Looking Ahead

NHTSA has begun working on a regulatory proposal to require V2V devices in new light vehicles in 2016.The rulemaking for heavy vehicles will follow shortly after. It is anticipated that connected vehicles will appear on the roadways in 2016 or earlier.

In the meantime, the FHWA is developing policy positions, guidance, guidelines, whitepapers and practitioner tools to promote the smooth deployment of V2I technology by transportation system owners and operators. The FHWA said that they would issue initial guidance on V2I in late 2015. The initial guidance is intended to assist in planning for future investments and deployment of V2I systems.

On September 14, 2015, the U.S. Department of Transportation announced that up to $42 Million in next-generation Connected Vehicle technologies would be awarded to New York City, Wyoming and Tampa, Florida, in an effort to reduce congestion, greenhouse gas emissions and crashes.

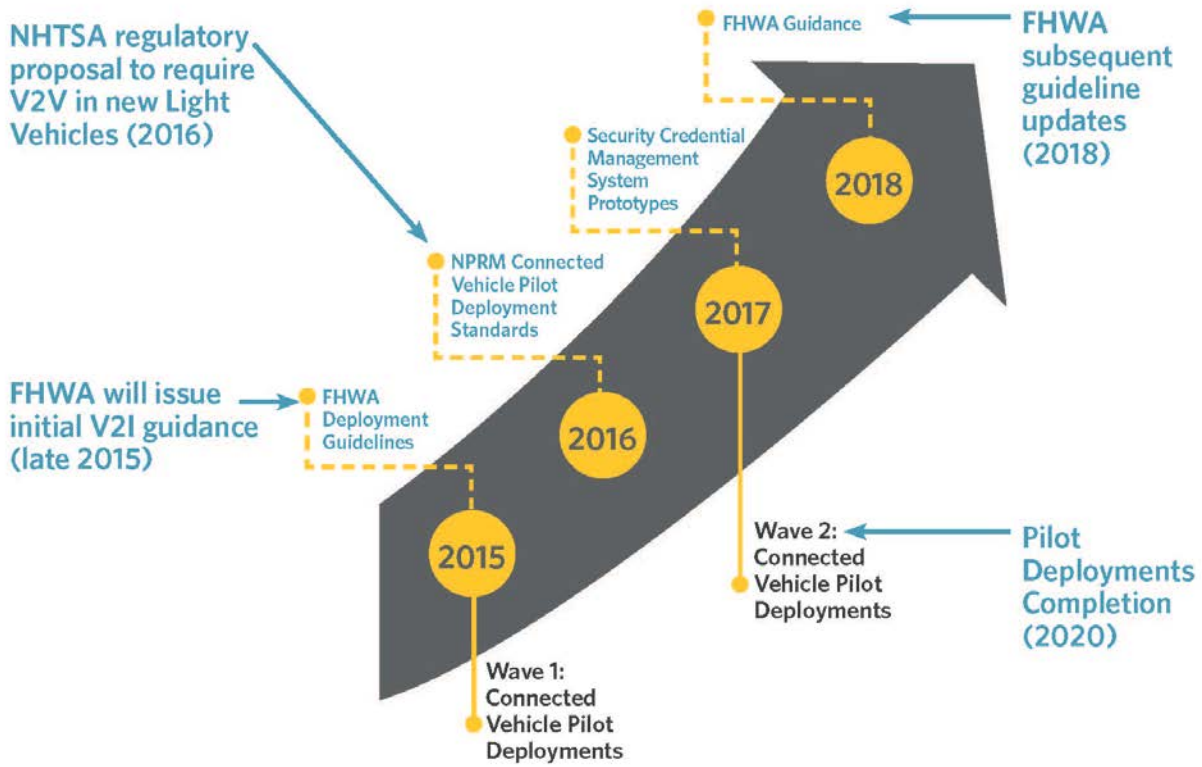


Figure 7. Connected Vehicle Model Pilot Deployment and NHTSA Rulemaking (2015 to 2020)

Champions/Drivers

USDOT has sponsored most of the research and development of the connected vehicle technology to date. Approximately $445 million was invested in the connected vehicle technology by USDOT between 2003 and 2012. This includes 80% of the Safety Pilot project that occurred in Ann Arbor, MI.

As indicated, FHWA plans to issue deployment guidelines in 2015 and NHTSA will continue announcing decisions on light and heavy vehicles in the coming years. In the USDOT ITS Strategic Plan[2] (2015 – 2019), the following key initiatives are included:

- Strategic priorities
    - Realizing CV implementation
    - Advancing automation
- Connected vehicle program
    - Focused on adoption and eventual deployment of the system

Efforts by DOT and the automobile industry to develop V2V technologies have largely focused on developing and testing needed components including:

- Hardware to send and receive data among vehicles
- Software applications to analyze data and identify potential collisions
- Vehicle features that issue warnings to drivers of these potential collisions
- A security system to ensure trust in the data that are being communicated among vehicles

Based on DOT research and the ITS JPO-funded AASHTO analysis of infrastructure needs and deployment approaches, FHWA guidance will identify high-priority applications that local communities should consider installing, including:

- V2I safety applications (crash warnings at traffic signals, etc.)
- Dynamic mobility applications
- Road-weather applications
- Environmental applications

All of these are key factors driving the advancement of connected vehicle technology.

Benefits of Implementation

NHTSA released a comprehensive research report on Aug 18, 2014: *Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application*[3]. This report includes preliminary estimates of safety benefits that show two safety applications — Left Turn Assist (LTA) and Intersection Movement Assist (IMA) — could prevent up to 592,000 crashes and save 1,083 lives per year. Put another way, by providing advance warning, V2V technology could help drivers avoid more than half of these types of crashes that would otherwise occur. LTA warns drivers not to turn left in front of another vehicle traveling in the opposite direction and IMA warns them if it is not safe to enter an intersection due to a high probability of colliding with one or more vehicles. Additional applications could also help drivers avoid imminent danger through forward collision, blind spot, do not pass and stoplight/stop sign warnings.

[2] http://www.its.dot.gov/strategicplan/
[3] http://www.nhtsa.gov/About+NHTSA/Press+Releases/NHTSA-issues-advanced-notice-of-proposed- rulemaking-on-V2V-communications

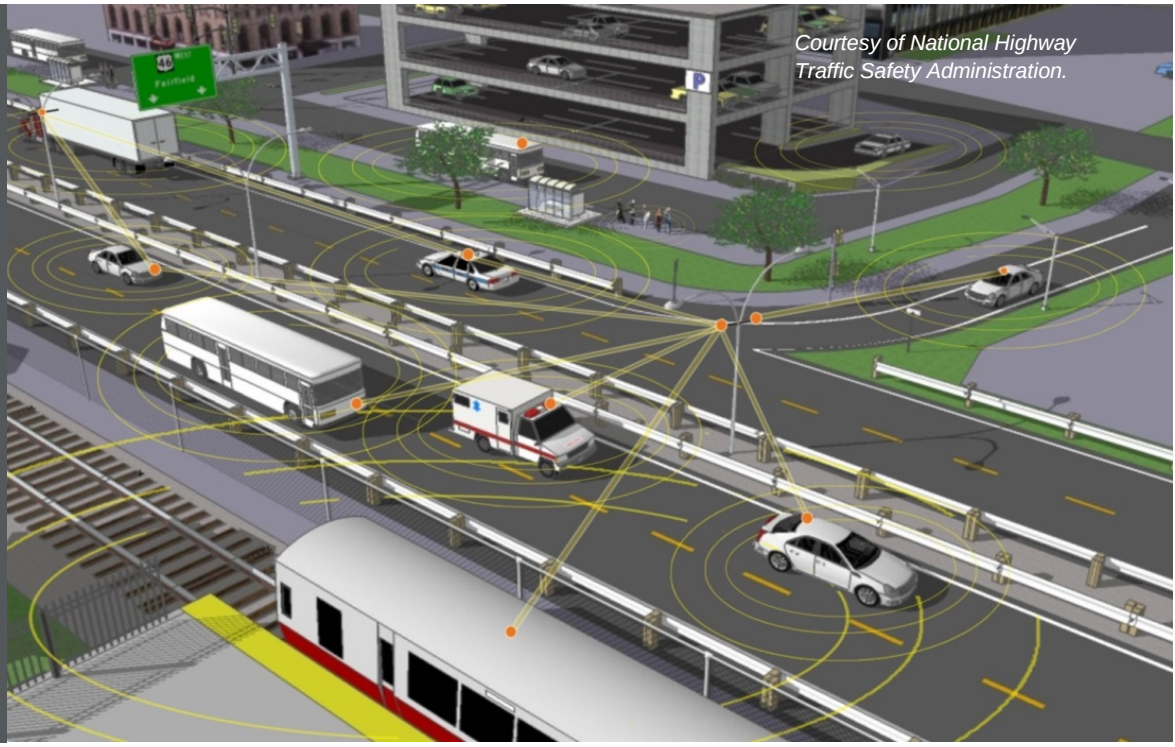


Figure 8. Visual Representation of V2V Communication

Also according to USDOT, by providing warnings to drivers, V2V technologies have the potential to affect or eliminate 76 percent of all potential multi-vehicle crashes involving at least one light-duty vehicle.

In addition to the safety benefits, connected vehicle technology has the potential to increase the roadway capacity and harmonize the speed on future managed lanes.

AV/CV Project Case Studies and Applications

FDOT Projects

Florida Automated Vehicle Initiatives

AV technology holds significant potential for efficiency and safety improvements within the State of Florida. Specifically, we anticipate that it has the potential to reduce the number of U.S. traffic crashes (5.3 million in 2011), traffic-related injuries (2.2 million in 2011) and traffic-related fatalities (32,000 deaths in 2011) since over 90 percent of all traffic crashes are attributable to human error. The societal cost of traffic crashes in the U.S. is estimated to be over a $900B annual drain on the economy.

AV technology will also vastly increase highway capacity and fuel economy by allowing vehicles to optimize acceleration and deceleration to reduce vehicle headways. New options for the Transportation Disadvantaged (elderly, physically challenged and children) can be provided enhancing their quality of life and that of their families and associates. New efficiencies in productivity for freight and transit systems can improve productivity, profitability and efficiency of goods distribution. Technological enhancements are nearing readiness for market introduction as evidenced by announced plans of many of the vehicle OEMs and aftermarket system suppliers.

The Florida legislature identified these significant transformative benefits to the State by passing legislation in 2012 allowing AV and CV research, development and testing on public roads. Sixteen states introduced legislation related to autonomous vehicles in 2015, and currently, six states enacted autonomous vehicle legislation, including Florida. As the lead stewardship agency of the State's transportation facilities, FDOT is taking actions to bring this vision to reality with a variety of pilot deployment projects, research projects, policy analyses, planning efforts, stakeholder workshops and symposia, and eventually permanent and sustained deployment of AV and CV systems and technology that enhance livability in the State.

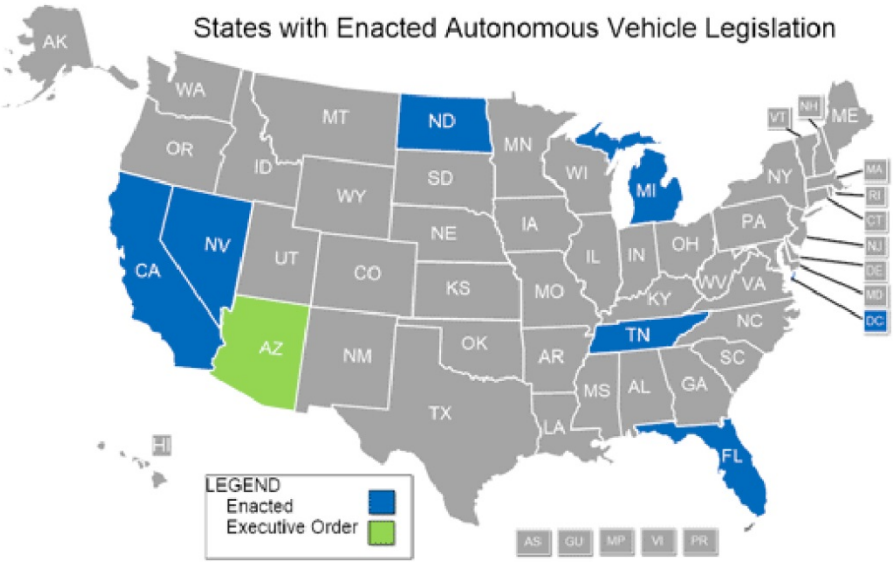


Figure 9.
U.S. States Autonomous Vehicle Legislation

Courtesy of © National Conference of State Legislatures (NCSL).

As one of the first steps toward the long-term vision of transformative mobility with AV technologies, FDOT developed Working Groups in the Spring of 2014 to bring stakeholders across the State together to address opportunities and challenges associated with implementing autonomous and connected vehicle technology on Florida roadways. Three Working Groups were identified:

1. Technology and Infrastructure
2. Policy
3. Modal Applications — Freight, Transit and Transportation Disadvantaged

Each Working Group is comprised of individuals from across the State of Florida who represent organizations and agencies that may benefit from or be impacted by these technologies. Working Groups have identified other strategic partners who have offered insightful knowledge of the industry to help address the challenges and opportunities as appropriate.

The Automated Vehicles Modal Applications Working Group is focusing on the areas of transit, transit disadvantaged and freight. Statewide open dialogue is being facilitated between the stakeholders and they are evaluating the opportunities and challenges associated with the technology in each of the modal areas. Questions that are being evaluated include:

- How can AV and CV technologies be used to enhance safety and efficiency of freight and transit operations?

- What obstacles may hinder the deployment of AV and CV technologies to support provision of services to the mobility disadvantaged by FDOT and other state and local agencies? How can those obstacles best be addressed?
- What can FDOT do to influence the rate of adoption of AV and CV technologies into freight and transit operations?

The state of the technology is also being monitored by researching pilot projects from around the world, and keeping the stakeholders informed of the latest developments in the industry.

Figure 10.
SARTRE Road Trains Test with Several Vehicles in High Speed

Courtesy of Volvo Pilot Project from Barcelona, Spain (SARTRE Project) – Right to Ride.

Autonomous vehicle applications will provide great benefits for trucking and freight delivery as well. These benefits include platooning or convoy technology, automated parking and backup assist, and aerial drones. Truck platooning technology concepts allow a lead driver to drive manually while several follower trucks operate at NHTSA level 3. Several projects in Europe are currently ongoing. The Safe Road Trains for the Environment (SARTRE) project with Volvo trucks and a variety of other university and private partners demonstrated success in 2014 with one leader and one follower truck. Other similar pilot projects are occurring in Sweden and Austria. California PATH will begin a truck platooning pilot project in 2015. USDOT has also tested truck platooning concepts. These projects have demonstrated 10 percent improvements to fuel economy through reduced aerodynamic drag. Army TARDEC has explored convoying technologies for military vehicles. While not specifically for freight, the University of Minnesota has developed Level 2/3 AV and CV technologies for assisting snowplow drivers. Although snow is not a factor in some states, the assistive technologies are applicable to heavy vehicle operation in other types of inclement weather including heavy rain, fog and smoke.

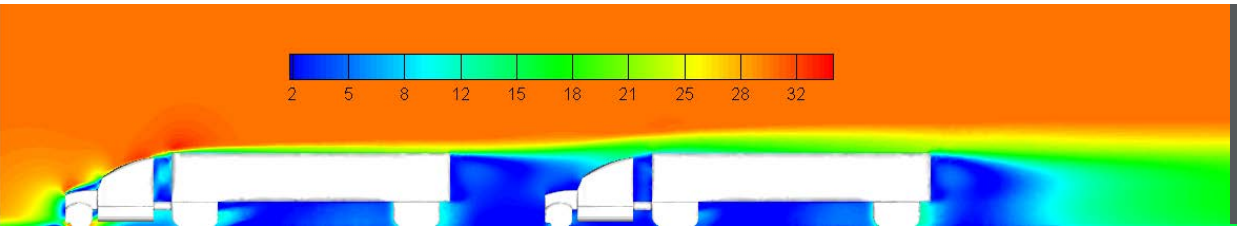


Figure 11. The Aerodynamic Benefits of Truck Platooning

Courtesy of Auburn University; Andrew Watts graduate student in Aerospace Engineering, Josh Batterson Research Faculty in Aerospace Engineering, and David M. Bevly Professor in Mechanical Engineering.

Other technology advancements will also affect freight operations in the future. Aerial drones present an alternative to existing freight logistics models by delivering small parcels to customers from local distribution centers. Amazon has demonstrated several test units for short distances. DHL will begin testing aerial drone-based delivery of time-critical medicines to customers on a small island off the coast of Germany in 2015.

Figure 12. A Potential Future Delivery System

Automation in various forms has been used at many maritime port operations worldwide for over twenty years. Automated container stacking, trailer positioning and container delivery systems are becoming more and more commonplace at major ports to improve safety, security and efficiency. Automated Guided Vehicles (AGVs) have long operated in controlled environments (e.g. indoor factories) with small (i.e. small with respect to drayage containers) parcels (e.g. Frog Technology)[4]. Automated systems for outdoor port operations are starting to emerge since the routes that drayage operators currently take are very deterministic.

[4] http://www.frog.nl/Solutions/Technology/Frog_Technology.html

Figure 13. Port of Los Angeles

The mining industry has also been embracing automation for over 10 years (e.g. Cat® MineStar™)[5]. Unprecedented improvements to operator safety, equipment availability and site productivity have been achieved with remotely-controlled, semi- and fully autonomous operation of mining equipment. Mining brings many challenges with it and, similar to the distribution of components in a manufacturing process, the routes and activities are very deterministic. Mining vehicles have become super-massive over time to maximize efficiency and profitability. In some mining operations, 200+ton trucks are now completely autonomous.

Figure 14. Caterpillar MineStar Technology

[5] http://www.catminestarsystem.com/

The typical freight supply chain from seaports is from port to truck and then to rail. Each modal change results in delay. Demand (trucks) typically vastly outweighs supply (available containers) creating significant truck queues in and around ports. Congested highways and arterial streets create additional challenges for truck mobility resulting in wasted fuel and high emissions. Alternative concepts for freight distribution have been proposed in recent years, and some have moved beyond the concept stage into prototyping, such as TTI's Freight Shuttle System, which is scheduled to be completed by the end of 2015. The Freight Shuttle is composed of independent, flexible, truck-like container vehicles (e.g.TTI freight shuttle)[6] operating on a dedicated, grade-separated guideway. Another recent concept comes from Oak Ridge National Laboratory[7].

Courtesy of Texas Transportation Institute (TTI).

Figure 15. Freight Shuttle Trailer

Connected vehicle applications for freight have been in development by USDOT, State and universities in the U.S. and worldwide for over 15 years. A number of test-bed locations for technology evaluations have been deployed in California, Michigan, Arizona, Virginia, New York and Florida. Truck priority at traffic signals was first demonstrated in approximately 2002. Other low-tech systems (based on weight and length) for detecting trucks approaching traffic signals to provide extended yellow or green times were developed in the mid 1990s. In 2008, New York first demonstrated DSRC-based CV applications on long-haul trucks on their freeway test bed. The USDOT safety pilot in Ann Arbor, MI, included CV equipment (here-I-am and driver assistance warnings) on a small group of trucks during the year-long evaluation of the technology. CV technologies on trucking can have a large near-term impact due to the fact that crashes involving heavy trucks have high severity, frequently including fatalities and causing massive delays when highways are blocked for long periods of time while trucks are removed from the right-of-way.

AV/CV technologies hold promise for improving the efficiency and safety of transit operations. CV technologies have been used for over twenty years now in hundreds of locales for providing priority green time at traffic signals, also known as Transit Signal Priority (TSP) or Bus Signal Priority (BSP). Most TSP/BSP systems over the last 20 years have used a special hardware device installed on each bus to send a special communications signal (usually infrared) to another special receiver device at each intersection. That device then commands the traffic signal to either provide additional green time for the approaching vehicle to continue through without

[6] http://tti.tamu.edu/freight-shuttle/
[7] https://www.youtube.com/watch?v=e_Q_OICXeFs

having to stop, or it will make the green signal appear sooner than normal. A countywide system is currently being installed in Miami-Dade County that uses internet communications to connect all of the traffic signals for priority operations without additional hardware.

Figure 16. Vehicle-to-Vehicle (V2V) Communications

Courtesy of National Highway Traffic Safety Administration — safercar.gov.

Connected vehicle applications have also been in development for transit by USDOT, State, and universities in the U.S. and worldwide for more than 15 years. Test-bed locations for technology evaluations have been deployed in Ohio, Michigan and Arizona. The USDOT safety pilot in Ann Arbor, MI, included CV equipment (here-I-am and driver assistance warnings) on a small group of transit vehicles as well as trucks during the year-long evaluation of the technology. CV technologies on transit can have a significant near-term impact due to the fact that crashes involving buses have significant severity involving many injuries and traffic congestion. The USDOT CV program includes a number of applications for enhancements to transit services, including:

- Dynamic ridesharing
- Dynamic dispatch and routing
- Integrated electronic payment
- Route ID for visually impaired
- Smart Park and Ride
- Transit connection protection
- Transit stop request
- Right turn in front of transit vehicle warning
- Pedestrian in vehicle path warning
- Transit vehicle at stop warnings

Figure 17. NAVYA ARMA Autonomous, Driverless, Electric Shuttle

Autonomous vehicle applications for transit include precision docking, autonomous low-speed shuttles and alternative forms of transit services. Autonomous operation of standard-size buses is set to begin in New Jersey in 2015 on a controlled test track in Fort Monmouth. Similar tests are planned in California in the Bay area on PATH facilities. CACC and lane-keeping systems have previously been studied at PATH for 15 years. Autonomous low-speed shuttles are seeing many pilot deployments, primarily in Europe. The NAVYA ARMA is a 100-percent electric and autonomous transport vehicle that was launched in October 2015 after 10 years of research. Operating at the highest level of autonomy possible, Level 5, the NAVYA ARMA is the first entirely autonomous series vehicle. It accommodates up to 15 passengers and can safely drive up to 45 km/h in mixed-use environments with pedestrians and bicyclists, mostly on private sites. The CityMobil2 project is deploying autonomous transit shuttles in over 12 different environments. Most environments are tourist areas, like the western coast of Sardinia where there is a simple single line along a popular beach. Other deployments envision several interconnected lines that could be used to route passengers from point to point along new routes. Alternative forms of transit include concepts such as the Straddling bus being developed in China and the Hyperloop. The Straddling bus operates on rails on each side of a freeway while private vehicles drive on the freeway underneath the bus like in a tunnel. The Hyperloop concept (and similar concepts that have been proposed over the last 40+ years) would transport small groups of travelers in vacuum-tubes at miraculous speeds, such as San Francisco to Tokyo in 30 minutes.

FHWA Projects

FHWA Desk Reference and Tools for Estimating the Local, Regional and State-Wide Economic Development Benefits of Connected Vehicle to Infrastructure Deployments

A desk reference and accompanying tools are being designed to assist state, local and regional transportation decision makers as they plan and justify their investments in CV infrastructure applications. The desk reference and tools will assist in estimating the potential local, regional and State economic benefits, as well as the costs and economic development associated with implementation of CV technologies. The tools will leverage existing findings and incorporate risk analysis to account for the uncertainty on a large number of measurements, projections and assumptions.

Conclusion

What this means for the Transportation Industry

Autonomous and Connected Vehicle technology is advancing rapidly. This is largely due to the benefits in safety, mobility and environmental impacts that will be realized as a result of AV/CV integration into our transportation system. It is critical for public transportation agencies and private companies in the transportation industry to be prepared for the transition from our traditional transportation system to one that employs these technologies that will enhance safety, improve operations, and provide great economic advantages. In order to keep abreast of the ever-changing advancement of technology in the transportation system, it is recommended that public and private entities work together and remain engaged in the following areas:

- Observing and participating in U.S. and Global AV/CV work groups
- Identifying anticipated transportation infrastructure impacts
- Assessing transitional infrastructure needs
- Developing innovative solutions

The full benefits of vehicle automation can be achieved only through connectivity. By integrating connected and automated vehicles, we can improve the safety of our roads, expand our transportation capabilities and greatly extend mobility options to everyone, including the disabled and the elderly.

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